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Growth and Yield Prediction Systems

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PREFACE

The Ministry of Forests is responsible for managing the forest resource to maximize the immediate and long-run social and economic benefits for all British Columbians. The satisfactory discharge of this responsibility depends, to a large extent, upon our ability to evaluate the productive capacity of the land base, to estimate both the present and future condition of the existing forest resource, and to develop forest management regimes that optimize future yield. This report briefly describes the growth and yield prediction systems in use for forest management planning within the Ministry. With increasing forest resource use pressures on an ever diminishing forest land base, it is imperative that foresters are aware of the Ministry's growth and yield prediction systems and their appropriate application and use.

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INTRODUCTION

This report briefly describes the growth and yield prediction systems currently supplied by the British Columbia Ministry of Forests (MOF). Only those growth and yield prediction systems that generate estimates of stand volume are presented here. Site index curves, individual tree volume equations, and other important growth and yield tools are not described.

This report is intended for MOF and licensee personnel who are involved in preparing or reviewing MOF growth and yield predictions. Therefore, the reader is assumed to be familiar with growth and yield terminology and concepts, especially as they relate to the situation in British Columbia. Throughout the report, synthesis of information is stressed rather than technical detail.Relevant background information is provided for the growth and yield prediction systems, and examples are given to illustrate their proper use.

BACKGROUND INFORMATION ON GROWTH AND YIELD PREDICTION SYSTEMS

Definition of a Growth and Yield Prediction System

Growth and yield prediction systems, or models, are abstractions of reality. These models estimate the characteristics of the timber yield from a stand, given some information on initial conditions. Growth and yield prediction systems span a range of complexity. Both the simple, graphical volume-age curve and the complex, computerized stand growth model are growth and yield prediction systems.

Uses of Growth and Yield Prediction Systems

Growth and yield predictions are used to update forest inventories, provide input for forest management planning, evaluate stand management opportunities, and assess the impact of pests and fire on timber yield.

Responsibility for Providing Growth and Yield Predictions Within the MOF

The provision of growth and yield information is a responsibility shared by Inventory and Research Branches. Inventory Branch, in addition to maintaining and updating an inventory of the forest resource, is responsible for assessing the productivity of the land base, monitoring the growth of the resource, and providing estimates of the growth and yield of unmanaged stands.

Research Branch is responsible for developing managed stand yield tables and for undertaking studies to provide the data required for yield model development.

History of the Development of MOF Growth and Yield Prediction Systems

Perhaps the first estimates of the quantity and growth of British Columbia's timber resources were made in 1913 by H.R. MacMillan in his report on the first year of the new Forest Service (MacMillan 1913). The first yield tables were prepared in 1920 for hemlock, balsam, cedar, and spruce types in the Bella Coola and South Bentick Arm areas (Caverhill 1921). During the next three decades, growth and yield estimates were generally developed following the 'normal' yield table approach using information taken from fully stocked stands. Coincidentally, the first growth plots were established during the early 1920's, initially in coastal Douglas-fir and subsequently throughout the rest of the province. During this same period, initial research trials were established to quantify the response to various stand tending treatments. Preliminary yield tables, based on temporary sample plot data, were published in 1928 for several coastal species (hemlock, balsam, spruce, cedar, and Douglas-fir) and two interior species (ponderosa pine and lodgepole pine) (Caverhill 1929). Volume, yield, and stand tables for some of the principal timber species were developed in 1936 (B.C. Forest Service 1936). In 1947, normal yield tables, based on the periodic remeasurement of permanent sample plots, became available (B.C. Forest Service 1947).

Because of the inherent difficulties of applying normal yield tables to highly variable stand conditions, empirical yield tables were developed from temporary sample plot data. These data were collected during the first complete continuous forest inventory that began in 1951. The empirical yield tables were presented in 1957 and revised in 1961 as more samples became available (Fligg 1960). With the continuation of the inventory and the expansion of the database, the empirical yield tables quickly became outdated. Starting in 1963, volume- and diameter-age curves were produced using forest inventory plot measurements and harmonized-curve techniques.

All sample plot data were compiled to new size limits and utilization standards with the conversion of the forest inventory to metric units in 1976. By this time, the MOF had amassed a substantial temporary sample plot database. Also, computer power and statistical methods had advanced dramatically. To take advantage of these developments, Inventory Branch replaced the existing hand-drawn curves with mathematical curves. The empirical database was stratified by site class, species composition, and geographic region. Nonlinear

regression was used to fit the Chapman-Richards function to volume-over-age and diameter-over-age data in each stratum. The Site Class System was the primary source of MOF growth and yield predictions from the late 1970s until the early 1980s.

Development began in 1981 on the variable density yield projection system to respond to the need for more detailed yield predictions (Viszlai 1983). This system was designed to take advantage of the 1978 refinements in forest classification which make site index and crown closure estimates available. However, the variable density yield projection system has not been widely applied. Yield predictions are available only for pure species stands.

The Site Index System (formerly referred to as the Ek-Payandeh/Volume Ratio System) was developed in the mid-1980s as an interim measure until crown closure was available for all forest labels in the inventory Branch data bases. This system has been used widely for appending volumes to branch files and for supplying yield projections in the Timber Supply Area (TSA) analyses. Use of this system will be discontinued in 1991.

A revised Variable Density Yield Prediction (VDYPII) System is currently being calibrated and is scheduled for release in the spring of 1991. As with the earlier VDYP system, both an air (crown closure) and ground (basal area) approach will be available. Major revisions have been made in both the form of the equations and the calibration process. All projections will be based on polymorphic site curves.

The development of TASS (TREE AND STAND SIMULATOR) began in 1963 (8). In 1985, Research Branch published managed stand yield tables for coastal Douglas-fir generated by the TASS growth and yield model.

Classifying Growth and Yield Prediction Systems

By organizing growth and yield models within a classification system, a framework is provided for describing the MOF models and understanding how they relate to each other and to the entire family of growth and yield prediction systems. The most widely applied classification system is based on two important characteristics of growth and yield models. First, models are separated into two groups based on the quantities that the models predict. Second, these groups are further subdivided based on how stand density is modeled. Figure 1 illustrates this taxonomic structure and where the growth and yield models available in British Columbia fit into this framework.

Whole stand models predict unit-area quantities (i.e., volume per hectare and stand mean diameter). Individual tree models predict quantities associated with individual trees (i.e., tree heights, diameters, and crown lengths) and sum these to produce estimates of the yield per unit area. Of the whole stand models, only the variable density whole stand models allow the user to assess the effects on yield of variation in stand density. Of the individual tree models, only distant dependent models maintain a record of the point density around individual trees.

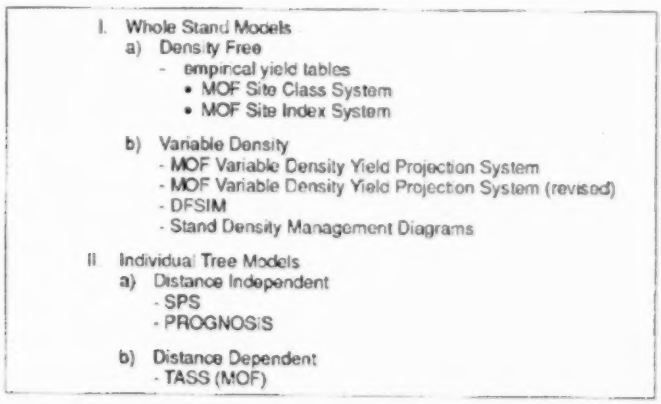

FIGURE 1. Classification system for growth and yield models.

Describing Growth and Yield Prediction Systems

What characteristics of growth and yield prediction systems should be discussed when describing a model? The model classification system presented in the preceding section suggests several important features. This section reviews these and other key attributes of growth and yield prediction systems. Later, we describe MOF growth and yield prediction systems in terms of these key attributes.

Growth and yield prediction systems are described in terms of the conditions to which they apply. Frequently, a model can be applied to either unmanaged stands (i.e., MOF whole stand models) or managed stands (i.e., TASS), but not to both. Some models can simulate the growth of mixed species stands while others can only generate yield estimates for pure species conditions. Models differ in their suitability for yield prediction in even-age, multi-layer, or uneven-age conditions. More subtly, models differ in terms of their suitability for extrapolation as opposed to interpolation. Individual tree models (e.g., TASS) tend to perform better than whole stand models when yield predictions are required for a condition that is outside of the range of existing experimental data. This suitability for extrapolation is important to consider when growth and yield models are used to produce yield estimates for silvicultural treatments (or other conditions) for which little data exists. Also, the estimation of current yield is subtly, but significantly, different from the prediction of future yield. Growth and yield prediction systems differ in their suitability for these two tasks. Similarly, models differ in their suitability for specific analyses. Whole stand models are frequently most appropriate for inventory updates and forest management planning applications. Compared to whole stand models, individual tree models often provide better simulations of treatment response and yield losses due to fire and pests.

A reference to the application environment should be included in the description of a growth and yield prediction system. Some models are not computerized and require the user to perform all calculations (e.g., Site Class System). Some computerized models have demanding hardware requirements that render them costly to run (e.g., TASS). Some growth and yield prediction systems are better documented, more user friendly, and better supported than other systems.

Growth and yield experts describe growth and yield models by analyzing model form, fitting techniques, verification efforts, and characteristics of the database. One of the many aspects of model form that is worthy of description is whether the model is composed of equations whose behavior is well controlled at the extremes (i.e., Site Class System). Where relevant, a model may be described in terms of the techniques used to develop it. Only a few models have been tested against independent data sets (e.g., TASS). Often, the description of a model includes a description of the data set used to calibrate the model.

Models can be described in terms of how they account for the factors that affect yield: stand age, site quality, stand density, treatment and history, geographic region, and stand structure. In the simplest case, a model will account for one of these factors by returning yield predictions appropriate for the average value of the factor (e.g., Site Class yield predictions that assume average stand density). A more detailed approach, to allowing the factors that are significant yield determinants to affect yield predictions, employs stratification. The range of a continuous variable is broken into discrete classes and a separate yield curve is developed for each class (i.e., Site Class Yield predictions that recognize four levels of site quality).

Growth and yield models can be described in terms of the output they provide and their input requirements. The demanding input requirements of some models preclude their use for some applications. Growth and yield prediction systems differ in terms of the detail provided in their output. Models with the most detailed output (e.g., TASS) are the most appropriate for evaluating silvicultural management alternatives.

A discussion of growth and yield prediction systems generally stresses predictions for healthy, established stands. However, depending on the application, a unified prediction of growth and yield requires evaluating additional factors: stand development from establishment to the free-growing stage, the risk of loss to fire and pests during stand development, and decay, waste, and breakage factors over time.

DESCRIPTION OF THE GROWTH AND YIELD PREDICTION SYSTEMS CURRENTLY USED BY THE MOF

Simple mathematical expressions are included in this section to describe the growth and yield prediction systems used by the MOF. These implicit equations state which variables are used to generate a yield prediction. This formulation eliminates algebra and presents the fundamental relationships on which a yield prediction system is based. For example, a volume-age curve, where the prediction of stand volume is based solely on stand age, is described by the following implicit equation:

$$VOL = f(AGE).$$

This implicit equation readily suggests that a volume-age curve cannot be used to assess the effect on stand volume of a specific silvicultural treatment.

The following variables and abbreviations are used in this section:

AGE	=	Stand total age (years)
BA	=	Basal area (m2/ha)
CC	=	Crown closure (%)
DIA	=	Quadratic mean stand diameter (cm)
DLM	=	Minimum merchantable diameter (cm)
FBA	=	Future basal area (m2/ha)
FIZ	=	MOF Forest Inventory Zone
GTG	=	MOF Growth Type Group
RBA	=	Relative basal area
SI	=	Site index (m)
VOL	=	Stand volume (m3/ha)
VR	=	volume ratio

Unmanaged Stands

Site Class System

Description of the System

The Site Class System is the simplest growth and yield prediction system under consideration in this report. Volume and stand mean diameter are predicted from stand age. By stratification, the effects on yield of species composition, geographic location, and site quality are incorporated into predictions. That is, the system is a collection of pairs of curves: volume-age curves (VAC's) and diameter-age curves (DAC's). When the diameter limit and utilization standards are specified, one curve pair is associated with each combination of Site Class, GTG, and FIZ:

$$VOL = f(AGE)$$

$$DIA = f(AGE)$$

Database

The Chapman-Richards site class system is calibrated to the 50000+ samples in unmanaged stands that constitute the provincial temporary sample plot database. The VAC and DAC tables of coefficients provide useful information on each yield curve: stratum constituents (the FIZ's, GTG's, and Site Classes pooled to form a single curve), number of observations per stratum, and a regression equation fit statistic (R2).

Application Environment

The Site Class System is currently available as tables of coefficients that can be obtained from Inventory Branch. To obtain a yield estimate, the user must acquire these tables of coefficients, select the appropriate coefficient set, and calculate the yield estimate. Refer to Appendix 2 for an example of this procedure.

Input Requirements

To obtain an estimate of yield, the diameter limit and utilization standards must be specified. Second, stand age must be defined. Last, the stand must be classified as to Site Class, GTG and FIZ.

Output Provided

This system directly predicts stand volume and mean diameter. Volume estimates are available to a variety of utilization standards and diameter limits. Yield predictions 12.5 cm+ (and greater) include reductions for decay. Some yield predictions include reductions for decay. The tables of coefficients also report culmination of mean annual increment and culmination age. Refer to Appendix 2 for an example of Site Class System output.

Common Applications and Limitations

The Site Class System is best suited to predict yields of unmanaged stands where forest cover types are classified according to the old MOF inventory standards, superior yield prediction systems are not available, or generalized, average yield values are adequate. This system is appropriate for estimating current volumes for use in broad, forest level planning. The model structure is not suitable for yield estimation in uneven-age stands. Within the MOF, this system receives only occasional use to supply "first approximation" volume estimates or to provide a benchmark against which the predictions of newer systems can be compared. Some licensees with old inventories (cover types classified according to site class instead of site index, no estimates of crown closure, etc) utilize the Chapman-Richards site class system for forest management planning.

This system is reliable when used within the range of the empirical database to which it was fit. Longterm projections with this system may be inappropriate for tree species which have revised site index curves that differ in shape from the curves contained in Inventory Report No. 1 (Hegyi et al. 1979). Occasionally, adjustments for operational use are indicated in the tables of coefficients. The effects on yield of stand history, treatment, and density are not explicitly considered in this system. The Chapman-Richards site class system is not responsive to small changes in site productivity. The system only recognizes four broad site classes.

Additional Information

Additional information can be obtained by:

- Referring to Appendix 2 for an example of the input requirements, output provided, and use of this system, and
- Contacting Inventory Branch.

  Manager, Growth and Yield
  Inventory Branch
  Ministry of Forests
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  Victoria, B.C.
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  Telephone: (604) 387-7185
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Variable density yield projection system

Description of the System

Of the three unmanaged stand yield prediction systems under review in this report, only the variable density yield projection (VDYP) system (and revised VDTP) include a measure of stand density directly in the equations used to predict yield. Site index and stand age are also included in the VDYP yield equations. The effects on yield of species composition and geographic location are handled through stratification. That is, given FIZ and species composition, the VDYP system estimates stand volume, basal area, and average diameter from stand density, site index, and age.

The VDYP system consists of an interrelated series of equations that are combined to produce yield estimates. The specific combination of equations required to produce a yield estimate depends on the source of input data, completeness of input data, and whether a future or current yield is being estimated. The system can be used with stand data collected from either aerial classification or ground calls. Where ground call data is incomplete, the VDYP system will estimate important input values.

Database

The VDYP system is calibrated to all pure species samples in the entire MOF, unmanaged stand, temporary sample plot database. The published tables of VDYP system coefficients (Viszlai 1983) describe the database used to fit each individual yield curve. For each equation, the following database information is provided: stratum constituents (the FIZs and species pooled to form a single curve), descriptive statistics for each independent variable, and regression equation fit statistics.

Application Environment

Today, to obtain yield estimates from the VDYP system, users must compute the estimates themselves. Thus, the user must acquire the published tables of coefficients and by selecting the appropriate coefficients. Appendix 3 contains an example of this procedure.

Input Requirements

Yield predictions for a given pure species stand require site index, stand age, and a measure of stand density. The diameter limit, utilization standards, and FIZ must be specified. The published tables of coefficients list the MOF site index curve that must be used for each yield estimate.

The volume prediction equation is:

(a) VOL = f(AGE,BA,DIA,SI)

When the source of input data is aerial classification, equations are used to estimate BA and DIA:

(b) BA = f(AGE,CC,SI)

(c) DIA = f(AGE,CC,SI)

When the source of input data is ground classification, best results are obtained when all input variables are measured in the field. However, a series of equations are available to estimate some of the required input values if they were not measured:

(d) BA = f(AGE,SI)

(e) DIA = f(AGE,BA,SI)

To compute the yield at some point in the future, future basal area is estimated as:

(f) FBA = f(AGE,RBA,SI),

where relative basal area is the ratio between observed basal area and predicted basal area:

(g) RBA = f(observed BA, predicted BA)

The FBA value is used in equation (e) to estimate stand mean diameter in the future. These two values are added to AGE and SI to estimate future volume with equation (a). Refer to Appendix 3 for an example of the input requirements of this system.

Output Provided

The VDYP system generates estimates of stand volume, basal area, and mean diameter. Estimates can be obtained to several utilization standards and diameter limits. Some yield estimates include reductions for decay. Refer to Appendix 3 for an example of the output provided by this system.

Common Applications and Limitations

This system was intended for use where detailed stand information is available: site index, age, and some combination of basal area, mean diameter, and crown closure.

The system is only available for pure, unmanaged, even-age stands (leading species > 80% by volume). Treatment and stand history effects are not explicitly modeled. The system does not make use of new (stem analysis based) site index curves and will be replaced on 1991 with a revised version.

Additional Information

Additional information can be obtained by:

- Referring to the published tables of coefficients (Viszlai 1983),
- Referring to Appendix 3 for an example of the input requirements, output provided, and use of this system, and
- Contacting Inventory Branch.

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Site Index System

Description of the System

Currently, the Site Index System (formerly referred to as "Ek-Payandeh Volume Ratio") is used in all TSA plans and all MOF inventory updates. The system generates estimates of both stand volume and mean diameter. To account for the effects on yield of species composition and geographic location, yield curves specific to each FIZ and GTG combination were derived.

With this system, stand volume yield to a 7.5 cm diameter limit is predicted as:

VOL = f(AGE,SI)

and converted to predict the yield at larger diameter limits with a volume ratio multiplier:

VR = f(AGE,SI)

Therefore, volumes are easily computed to any minimum diameter limit greater than 7.5 cm. Stand mean diameter is predicted by a modified Chapman-Richards curve:

$$DIA = f(AGE,SI)$$

For polygon updates, estimated volume is multiplied by a stocking class factor to adjust the yield estimate to account for stand density.

When The Site Index System was introduced, increase volumes in mature stands often resulted for species calibrated and projected on polymophic site curves. This trend was found to be consistent with other functions using these curves. Before this was fully comprehended, two interim steps were imposed to control upper age projection:

1. volume coefficients were recalibrated on anamorphic site curves and used for all mature volume estimation by Inventory Branch. This included most coastal species and interior spruce and lodgepole pine.
2. age cut-offs were developed to constrain mature volume production based on polymorphic site curves. This "capping" process attempted to produce mature volumes compatible with those derived on anamorphic site curves.

The later application was developed for the TSA analyses where and uninterrupted flow of volume through to maturity is required for the forest estate model.

Database

The Site Index System is calibrated to the 50,000 samples in unmanaged stands that constitute the provincial temporary sample plot database.

Application Environment

The Site Index System is available in the PC YIELD program (version I - IV). An IBM-compatible PC with a math co-processor is required. Program YIELD can run interactively or in batch mode. A description of the data base and information useful for assessing the adequacy of the resultant yield curves have not been published.

Input Requirements

Program YIELD accepts input data for stands classified according to both the old and the new MOF forest classification systems. If a stand is classified according to the new MOF inventory standards, YIELD accepts the following input: species composition (species codes and percentages), stand age, stand height, FIZ, crown closure, stocking class, stand area, waste and breakage zone, and output required.

Output Provided

YIELD provides output in several formats. For long-term yield predictions, the user can obtain a simple yield table. Alternatively, when current yield is estimated, more detailed output can be obtained. YIELD can provide the following output: stand mean diameter, stand height, maximum mean annual increment, culmination age, and the volume yield by species to several diameter limits (incorporating decay, waste, and breakage factors).

Common Applications and Limitations

The Site Index System is used by the MOF for inventory updates and forest management planning. The YIELD program generates polygon updates for the Forest Inventory Planning File (FIP) and long-term yield predictions for timber supply analyses.

This system is available for all species groups and geographic regions in the province (as categorized by GTG and FIZ). However, the structure of this system indicates that it is not well suited to estimating the yield of uneven-age stands. The system cannot be used to simulate the effects on yield of variation in treatment and stand history. In some cases, (polygon updates) the system accounts for the effect on volume yield of variation in stand density for mature stands. The Site Index System will be replaced in 1991 by a revised Variable Density Yield Prediction system.

Additional Information

Additional information can be obtained by:

- Referring to Appendix 4 for an example of the input requirements, output provided, and use of this system, and
- Contacting Inventory Branch.

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Revised Variable Density Yield Prediction System

Description of the System

A revised Variable Density Yield Prediction (VDYP)system si currently being developed to replace all existing natural stand yield systems maintained by Inventory Branch. As with the earlier VDYP system, both and air and ground approach will be available, permitting an optional crown closure or basal area density control. Height has replaced site index as an independent varable and all projections will reflect stem-analyzed (polymorphic) site curves. Other major changes include the use of permanent sample plot data and independent calibration on immature and mature data bases. splining functions will be used to smoothe the rransition zone. Mixed species estimation will be based on pro-rated pure species volume estimates

With this system, stand volume afro all levels of utilization is predicted as:

VOL = f(AGE, HEIGHT & CROWN CLOSURE)for air aproach

VOL = f(AGE, HEIGHT & BASAL AREA) for ground approach

This functionality is repeated for diameter estimation.

Volume proection for the ground approach requires the addition of a basal area frunction:

BA (future) = f(BA(current), AGE(current), AGE(future) & HEIGHT)

Data Base

The revised BDYP system is calibrated on temporary sample plots and all available pemanent sample plots (establishment measurement only). coefficients will be stratified according to the current FIZ boundaries, but similar zones will be aggregated to take advantage of larger, more complete data bases. Future enhancements will include:

- calibration of basal area function with connected PSP data: and
- calibration on ecologically geo-referenced data bases.

Input Requirements

VDYP (revised) accepts continuous variable input data, such as:

- species to the nearest percent;
- actual age, height and crown closure or basal area;
- localization adjustments; and
- breast height age site index (ref. 50 years).

This is in keeping with specifications from the current Reinventory Program. Reductions for decay, waste and breakage will be imbedded in the system.

Output Provided

The revised VDYP model and coefficients are currently available in a PC application for all coastal species and one interior zone. This system is written in C and requires a math co-processor for quick computations. A multiple input version will be produced in 1991 with access to data for validation checks. The application of windows and graphics (see Appendix 5) has been included to facilitate use and analysis.

Estimates of volume, quadratic mean diameter, mean annual increment and top height are produced from the air approach. Estimates of volume, height and basal area, with an option for relative basal area adjustment, are produced from the ground approach. These will be available at 7.5/12.5/17.5/22.5+ cm for all species, coast and interior.

Common Applications and Limitations

The VDYP (revised) system will replace all existing MOF natural stand yield systems. Volume estimates and projections are compatible for both inventory update and TSA analyses applications. Comparisons with the previous site VAC's indicate improvements in accuracy and lower bias. Operational adjustment factors will be introduced in 1991 to reflect local conditions.

This system should not be used to simulate the effects on yield of variation in treatment and stand history, nor is it suitable for uneven-aged stand estimation and projection. Users should ensure that input values of site index and crown closure reflect local conditions. Average values of crown closure and site index are available from Inventory Branch for most regions of the province.

Additional Information

Additional information can be obtained by:

- contacting Inventory Branch:

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  1319 Government Street
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  Telephone: (604) 356-7185
  FAX: (604) 387-5999

Managed Stands

TASS

Description of the System

The Tree And Stand Simulator (TASS) is a distance dependent individual tree model. TASS grows trees in a three-dimensional growing space simulated within the computer. The model employs the crown as the center of competition for growing space. The crowns of individual trees add a shell of foliage each year and expand and contract asymmetrically in response to internal growth processes, physical restrictions imposed by the crowns of competitors, environmental factors, and cultural practices. The volume increment produced by the foliage is distributed over the bole annually and is accumulated to provide tree and stand statistics.

Database

In addition to stem analysis data and other research information, TASS is calibrated with remeasured permanent sample plot data. TASS coastal Douglas-fir yield predictions were calibrated to conform with the data from coastal B.C. plots in both managed and unmanaged stands. These predictions have been tested against Douglas-fir data obtained from the United States, France, and New Zealand (Mitchell *et al* 1985).

Application Environment

TASS growth and yield predictions are available in three formats. First, TASS predictions are available as published yield tables. Second, users can run TIPSY (Table Interpolation Program for Stand Yield) to obtain customized versions of these yield tables. TIPSY is a computer program, available from Research Branch, that contains the published yield tables. Third, in special cases, TASS runs can be requested from Research Branch.

The published yield tables contain an excellent guide to their use (Mitchell *et al* 1985). When using the published tables, the user may have to interpolate to obtain yield estimates for a specific regime. TIPSY performs yield table interpolations and runs on most IBM-compatible PCs. TASS is only available at Research Branch. It has substantial input data and hardware requirements.

Input Requirements

To use TIPSY and the published yield tables, the user must specify species composition, management regime, and site index. Management regime is defined by stand origin (planted or natural), initial density, and residual stocking after spacing.

Output Provided

TASS output is much more detailed than the output from any other system under consideration in this report. The following output is provided: close utilization volume yield to several diameter limits, basal area, stand mean diameter, trees per hectare, percent crown cover, culmination of mean annual increment, culmination age, reduction factors for operational use, stand table, and stock table. The published tables report yield at three meter increments of stand top height. Therefore, the user must refer to site index curves to convert output to a stand age basis. Refer to Appendix 5 for an example of TASS published yield table output.

Common Applications and Limitations

TASS is intended to provide growth and yield estimates for managed stands and as a research tool. TASS is commonly used to assess stand management opportunities in coastal Douglas-fir. It has been used to assess the effects of pests and disease on yield. TASS yield estimates are currently available for coastal Douglas-fir. Interim yield estimates are available for western hemlock and two interior species (spruce and lodgepole pine). These estimates are limited to pure, even-age stands. As all predictions begin at stand origin, TASS is not well suited to predict the future growth of existing stands. Relative to the other growth and yield prediction systems described in this report, TASS is difficult (and costly) to calibrate.

The published yield tables describe a limited number of alternative initial espacement and juvenile spacing regimes. TIPSY can generate yield reports for additional regimes by interpolating values from the published tables. However, these two formats do not provide information on many regimes of interest. Reduction factors for operational use are provided in the published yield tables to adjust TASS yield estimates for decay, waste, breakage, growth repression, irregular stocking, pests, and disease.

Additional Information

Additional information can be obtained by:

- Referring to the Douglas-fir managed stand yield tables (Mitchell *et al.* 1985),
- Running TIPSY,
- Referring to Appendix 5 for an example of the input requirements, output provided, and use of TASS published yield tables, and
- Contacting Research Branch:

Manager, Forest Productivity and Decision Aids

Research Branch
Ministry of Forests
31 Bastion Square
Victoria, B.C.
V8W 3E7
Telephone: (604) 387-6642
FAX: (604) 387-8197

Associated Models

The Forest Productivity and Decision Support Section of Research Branch has developed a system of models called SYLVER (Silverculture Yield Lumber Value Economic Return) that relate Silviculture to Yield, Lumber Value and Economic Return. SYLVER consists of TASS (to simulate tree growth), SAWSIM (to simulate bucking logs and sawing them into lumber and chips), and companion models that grade the products and determine their present value with the aid of FAN$Y (Financial Analysis System).

EXAMPLES OF THE USE OF GROWTH AND YIELD PREDICTION SYSTEMS WITHIN THE MINISTRY OF FORESTS

Growth and yield predictions are used by many groups within the MOF. Silviculture Branch personnel use growth and yield models to evaluate various stand management opportunities. For example, the regional silviculturalist will use growth and yield predictions to establish recommended treatment prescriptions within the region.

Recent work with TASS and a model called the Root Rot Simulator is of great interest to Protection Branch personnel. By linking these two models, the effect of Phellinus weirii root rot on stand development and yield was investigated.

Integrated Resources Branch personnel use growth and yield models to evaluate the financial and economic consequences of forest management options, such as the effect on long-run sustainable yield of allocating a portion of a TSA to another resource use.

Inventory Branch personnel use MOF growth and yield models to estimate the volume and average diameter of forest stands (also called polygons) described in forest cover maps. Volume and diameter estimates are appended to each polygon record of the Forest Inventory Planning (FIP) file. In this process, site index is produced from height/age estimates based on the leading species within the geographic area. Site index is determined for immature stands using curves developed from stem analysis data. Mature stand site index is calculated using site curves developed from temporary sample plot data. All volumes are netted down for decay, waste, and breakage and adjusted for stocking and area. Summaries of volumes and other statistics can be produced by map sheet, timber supply area, or management unit.

The Forest Resource Analysis Section uses MOF growth and yield prediction systems to help determine AACs. In this process, forest types are stratified into analysis units by GTG and Site Class to facilitate assessment. A yield table and an area-based weighted site index is produced for each analysis unit. Yield estimates for managed stands are supplied by Research Branch based on TASS simulations and supplementary growth and yield information.

FUTURE DEVELOPMENTS IN MOF GROWTH AND YIELD PREDICTION SYSTEMS

Several projects are underway to improve the growth and yield prediction systems used by the MOF. A new variable density yield projection system is being developed for release in 1990. Projections rely exclusively on stem analyzed site curves. PROGNOSIS, the individual tree distance independent model that has received extensive use in the Rocky Mountain region of the United States, is being calibrated for uneven-age stands in the B.C. interior. Inventory Branch is coordinating these two projects as well as the development of a new decay/waste model. Emphasis will shift from FIZ to Ecologically based strata.

Research Branch is testing and improving the TASS interim coefficients for coastal western hemlock, interior lodgepole pine, and interior spruce. In addition, they are modifying TIPSY to render it more user friendly.

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APPENDIX 1: Glossary of terms

Close Utilization. The falling and bucking standard applied at harvest: 30 cm stump height and a 10 cm top.

Forest Inventory Zone (FIZ). A broad geographic area within B.C. The province is divided into 12 FIZ identified by the letters A - L.

Growth Type Group (GTG). A collection of forest types that exhibit similar growth patterns. GTGs are defined by the primary and secondary species in the type. Seventeen GTGs are recognized and identified by the letters A - Q.

Site Class. The MOF site index groups. Four Site Classes are recognized: Good, Medium, Poor, and Low.

Timber Supply Area (TSA). A forest land unit for which Timber Supply Area planning is conducted.

APPENDIX 2: Example using the Site Class System to provide yield estimates

The following example illustrates the use of the Site Class System to generate yield estimates.

For a given stand, estimates of stand volume and mean diameter at stand total age 80 are required. This stand is located in FIZ B, classified into GTG A and Site Class P. Yield estimates, net of decay, will be based on close utilization standards and a 17.5 cm diameter limit.

The appropriate table of volume-age curve coefficients is selected based on the FIZ, GTG, Site Class, utilization standards, diameter limit and decay specifications. This table, provided by Inventory Branch, is reproduced in this appendix (Table A-1). Table A-2 is the associated set of diameter-age curve coefficients. From the VAC table, the appropriate volume-age curve can be selected, VAC # 3419-B.

The Site Class System estimate of stand volume at 80 years total age is:

VOL = b1*(1-exp(b2*(AGE-b4)))**b3
= 390.5535*(1-exp(-0.0430*(80-0)))**5.9708
= 390.5535*(1-exp(-3.44))**5.9708
= 390.5535*(1-0.0321)**5.9708
= 390.5535*(0.9679)**5.9708
= 390.5535*(0.8230)
= 321 m3/ha

The Site Class System estimate of quadratic mean stand diameter at 80 years total age is:

DIA = DLM + d1*(1-exp(d2*AGE))**d3
= 17.5 + 39.4699*(1-exp(-0.0072*80))**1.5045
= 17.5 + 39.4699*(1-exp(-0.576))**1.5045
= 17.5 + 39.4699*(1-0.5621)**1.5045
= 17.5 + 39.4699*(0.4379)**1.5045
= 17.5 + 39.4699*0.2887
= 29 cm

APPENDIX 2. (Continued)

TABLE A-1. Site Class System volume-age curve coefficient table

FIZ: B

$VOL = b_1 (1 - e^{b_2(AGE-AGE_0)})^{b_3}$

Volume-age curve index by growth type and site volumes are net for decay only; close utilization (10 cm top) $AGE_0 = b_4$

Growth type	Site	VAC No.	DBH Limit: 17.5 cm+			Coefficients			
			Yield at cul. age m^3	Cul. age years	Max. MAI m ha	b_1	b_2	b_3	b_4
A - F, FPI, F Decid, PW	G	3417-B	649.1	60	10 8	1023.1279	-0 0342	3 3114	0 0
	M	3418-B	465.1	59	7 9	616.7332	-0 0607	9 9966	0.0
	P	3419-B	281.0	68	4 1	390.5535	0 0430	5 9708	0.0
B - FC, Cy, FH, FS	G	3393-B	860.2	70	12 3	1481.7158	0 0238	2 5880	0.0
	M	3420-B	580 8	66	8 8	791.4966	0 0471	6 7938	0.0
	P	3394-B	330.5	91	3.6	481.0842	-0 0282	4 6840	0.0
A&B - FIR TYPES	L	3395-B	145 8	95	1 5	182.5049	-0 0455	16 7712	0 0
E - CEDAR TYPES	G	3396-B	447 3	56	8 0	1112.2561	0 0140	1 4949	0 0
	M	3421-B	655 5	108	6 1	843.6713	-0 0362	12 3929	0 0
	P	3422-B	423 3	111	3 8	534.5437	-0 0379	15 6422	0 0
	L	3399-B	161 2	150	1 1	231.9144	-0 0178	5 0735	0 0
F - H, HP1, H Decid	G	3423-B	715 0	56	12 8	1382.5620	-0 0231	2 0608	0 0
	M	3424-B	369 0	56	6 6	1100.4153	-0 0110	1 4033	0 0
	P	3425-B	256 8	91	2 8	362.7671	0 0305	5 3727	0 0
G - HF, HC, HB, HS	G	3426-B	635 9	56	11 4	1056.2534	0 0319	2 7707	0 0
	M	3427-B	629.9	98	6 4	919.2861	0 0258	4 5346	0.0
	P	3428-B	493.8	102	4 8	573.9463	0 0639	101 8266	0.0
H - BALSAM TYPES	G	3406-B	832 8	73	11.4	1089.9741	0 0494	9 7771	0.0
	M	3407-B	647 0	93	7 0	875.8159	0 0345	7 3320	0.0
	P	3408-B	413.0	109	3 8	528.5667	0 0368	13 5420	0.0
IJK - SPRUCE TYPES	M	3409-B	632 8	66	9 6	772.1528	0 0777	33 5631	0 0
	P	3410-B	406 9	86	4 7	494.6194	0 0592	31 7036	0 0
L - PURE PI DO NOT USE	M	3411-B	185 4	67	2 5	237 2196	0 0406	5 2920	0 0
M - PI Conif. DO NOT USE	M	3412-B	419 2	116	3 6	576 1023	-0 0251	6 4126	0 0
	P	3413-B	124 9	84	1 5	155.5339	-0 0536	19 7354	0 0
O - D Conif. DO NOT USE	G	3429-B	342 7	27	12 7	496.5466	0 0987	5 1358	0 0
	M	3430-B	295 9	41	7 2	410 8875	-0 0740	6 6653	0 0
P - D Decid, Mb	G	3431-B	289 1	27	10 7	427 1001	0 0878	3 9776	0.0
Q - COTTONWOOD TYPES	G	3416-B	126 9	17	7 5	359.0737	-0 0280	0 8295	5 0
Q - COTTONWOOD TYPES	M	3085-B	169.4	69	2.5	281.5044	-0 0260	2 8002	0.0

APPENDIX 2. (Continued)

TABLE A-2. Site Class System diameter-age curve coefficient table

FIZ: B

EQN: $D = Dlim + b_1 (1 - e^{b_2 (AGE)^{b_3}})$

Diameter/age curve index by growth type, site class, VAC #.

Dlim = 17.5 cm

Growth type		Site Class	VAC No.	Coefficients			Remarks	N	R^2 %
Letter	Species comp.			b_1	b_2	b_3			
A	F FPI F Decid Pw	G	3417 B	1015 32211438	-0 00016619	0 90688012		145	68 23
		M	3418 B	53 89880765	-0 00763955	1 36346322		421	76 66
		P	3419 B	39 46986713	-0 00720098	1 50454573		222	62 60
B	FC, FCy, FH, FS	G	3393 B	49 78458380	-0 01646915	2 03635445		66	64 00
		M	3420 B	37 21728004	-0 01550327	1 89938334		205	74 06
		P	3494 B	24 27454755	-0 01623948	2 23179534		130	53 88
AB	FIR TYPES	L	3395 B	24 57048027	-0 00664856	1 77070691		50	44 68
E	CEDAR TYPES	G	3396 B	56 48718713	-0 01436391	1 61294690		86	35 91
		M	3421 B	43 28730745	-0 02978042	8 37318348		193	43 02
		P	3422 B	31 03467440	-0 01966304	2 58966597		98	14 91
		L	3399 B	15 41191379	-0 01842893	4 71229437		65	20 17
F	H, HPI, H Decid	G	3323 B	60 22736820	-0 01091724	1 74052341		109	87 15
		M	3424 B	49 02398412	-0 01130552	2 20578594		92	69 29
		P	3425 B	1160 66118290	-0 00003418	0 85438467		30	54 54
G	HE, HC, HB, HS	G	3326 B	47 83144561	-0 01630879	2 12920725		144	83 10
		M	3427 B	40 06872937	-0 02076228	4 24256843		274	68 88
		P	3428 B	22 37983238	-0 05558184	82 14422138		71	45 53
H	BALSAM TYPES	G	3306 B	44 41086281	-0 03539568	9 52503020		61	42 66
		M	3407 B	36 60080208	-0 02737018	8 81976815		255	31 88
		P	3408 B	23 12349997	-0 02189705	7 34115697		116	46 21
JK	SPRUCE TYPES	M	3409 B	35 06098395	-0 01772586	1 96742129		56	38 70
		P	3410 B	27 14079041	-0 01404710	2 45811445		10	72 89
O	D Conif	G	3429 B	18 98972534	-0 04077795	1 44671443		17	64 09
		M	3430 B	18 52911324	-0 02607343	1 19067367		49	32 04
P	D Decid Mb	G	3431 B	295 78893539	-0 00019931	0 64848726		34	21 06
Q	Cot Types	G	3416 B	221 22458121	-0 00137695	0 87951655		85	76 09
		M	3085 B	42 73318834	-0 01065027	1 77089480		81	40 30

APPENDIX 3. Example using Variable Density Yield Projection to provide yield estimates

The following example illustrates the use of the VDYP system to generate yield estimates. For a 50-year-old (total age) pure spruce stand in FIZ H, estimates are required of stand volume, mean diameter, and basal area at stand total age 70. Whole stem volumes to a 7.5 cm diameter limit are required. The following information on this stand is available from ground classification:

basal area	= 40 m^2/ha
MOF 1979 site index	= 20 m
stand age	= 50 years

The appropriate tables of VDYP system coefficients are located within reference (Viszlai 1983) based on FIZ and species composition. Utilization standards and diameter limits determine the appropriate coefficient sets within these tables. The tables relevant to this example are reproduced from reference (Viszlai 1983) in this appendix.

Given the information available in this example, we estimate future yield by:

- computing the basal area expected by the VDYP system at current stand total age 50;
- computing a relative basal area factor that expresses the difference between observed stocking and expected stocking;
- predicting stand basal area at total age 70;
- predicting stand mean diameter at total age 70; and
- predicting stand volume yield at total age 70.

When the VDYP system is used to predict the basal area of the existing stand, its estimate is:

```
XBA = b1*SI*((1-exp(b2*AGE))**b3)*exp(b4*SI)
XBA = 2.6618*20*((1-exp(-0.0558*50))**6.6277) *
      exp(-0.0219*20)
XBA = 54.2071 m²/ha
```

Therefore, the relative basal area of the existing stand is:

```
RBA = observed BA/expected BA
RBA = 40/54.2071
RBA = 0.7379
```

Predicted basal area at total age 70 is:

```
FBA = RBA*b1*SI*((1-exp(b2*AGE))**b3)*exp(b4*SI)
FBA = 0.7379*2.6618*20*((1-exp(-0.0558*70))**6.6277) *
      exp(-0.0219*20)
FBA = 43.7272 m²/ha
```

Predicted stand mean diameter at stand total age 70 is:

```
DIA = DLM+b1*SI*BA*((1-exp(b2*AGE))**b3)*exp(b4*SI+b5*BA)
DIA = 7.5 + 0.0658*20*43.7272 *
      ((1-exp(-0.0211*70))**2.0864) *
      exp(0.0037*20-0.0291*43.7272)
DIA = 17.6061 cm
```

Predicted stand volume at stand total age 70 is

VOL = b1*SI*BA*DIA*((1-exp(b2*AGE))**b3) *
exp(b4*SI+b5*BA+b6*DIA)

VOL = 0.0487*20*43.7272*17.6061 *
((1-exp(-0.0278*70))**0.9625) *
exp(-0.0201*20+0.0009*43.7272-0.0240*17.6061)

VOL = 420 m^3/ha

APPENDIX 4. Example using the Site Index System to provide yield estimates

TABLE A-3. Site Index System: output of program YIELD

Inventory Branch Net Volumes by Species

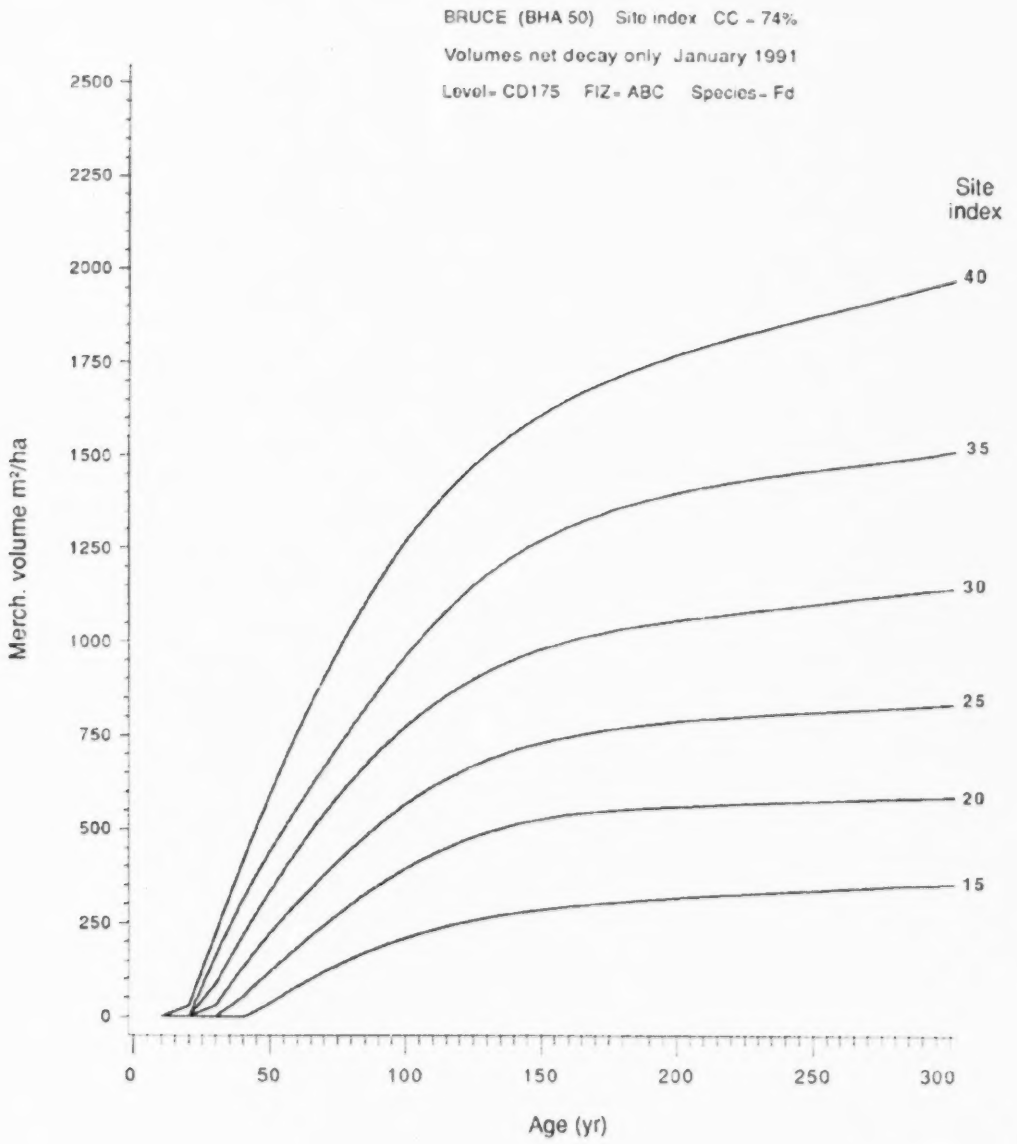
FIZ: B ITG: 1 Fir
Species: FD 100% WB Zone: Vancouver
Stocking Class: 0 Crown Closure Percent: 0
Waste and Breakage: Applied
Site Index (100): BRUCE 40
Area: 1.000 hectares

Culmination values:

Limit: 7.5	Volume: 694.5	Age: 97	MAI: 7.16
Limit: 17.5	Volume: 709.5	Age: 112	MAI: 6.34
Limit: 22.5	Volume: 703.4	Age: 120	MAI: 5.86

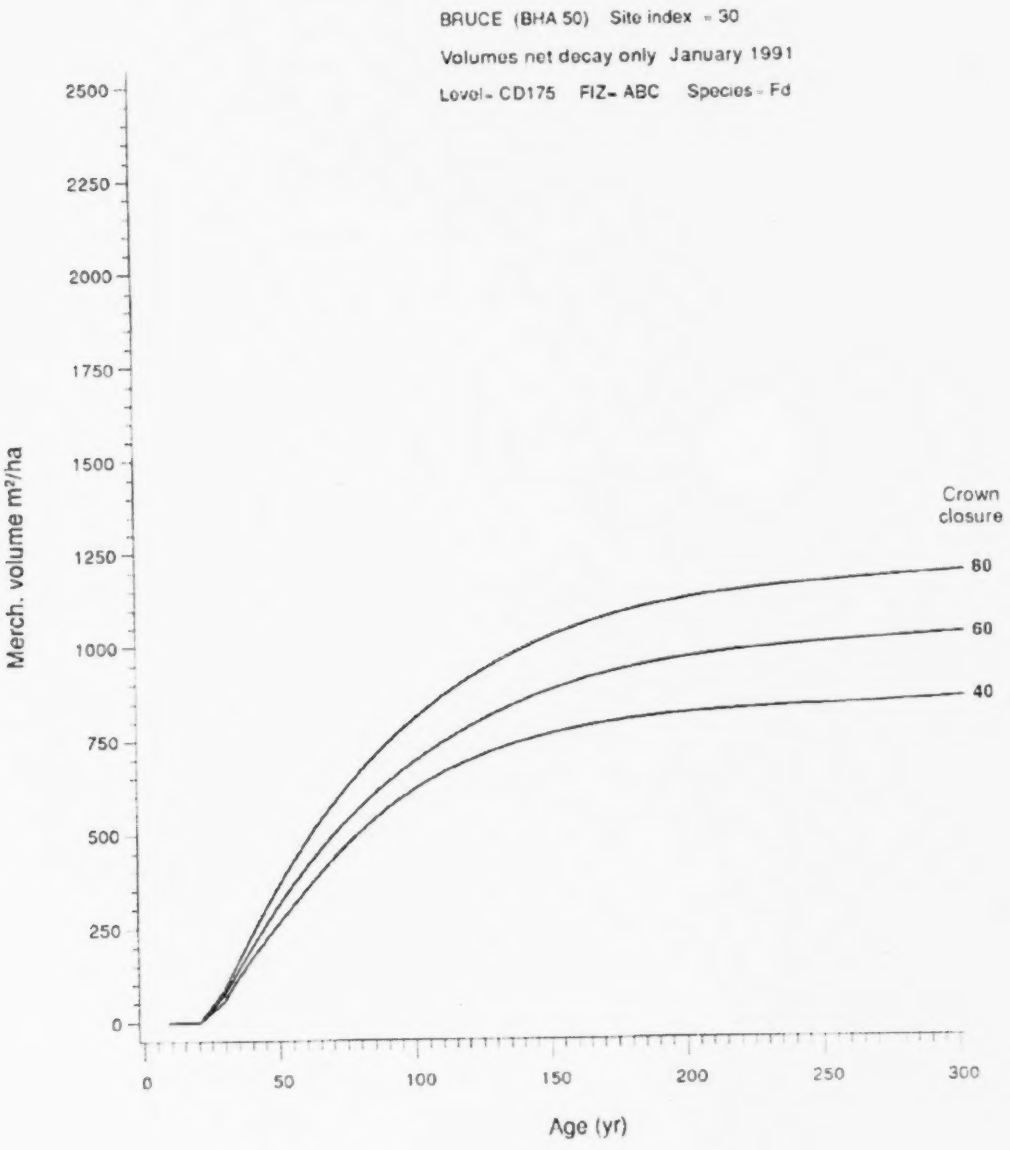
Total age	Volumes (m^3) by diameter limit (cm) 7.5	17.5	22.5
10	0.0	0.0	0.0
20	60.7	0.0	0.0
30	128.7	61.4	36.1
40	210.6	135.9	100.4
50	299.4	219.0	176.3
60	390.0	305.8	257.9
70	478.8	392.4	341.0
80	563.5	476.1	422.5
90	642.7	533.1	480.4
100	715.7	603.8	550.7
110	782.0	668.8	615.6
120	841.9	728.0	675.3
130	895.4	753.7	703.5
140	935.9	792.8	743.5
150	935.9	792.8	743.5
160	935.9	792.8	743.5
170	935.9	792.8	743.5
180	935.9	792.8	743.5
190	935.9	792.8	743.5
200	935.9	792.8	743.5

APPENDIX 5. Example using Variable Density Yield Prediction System (revised), by site index/crown closure



APPENDIX 5. (Continued)

Variable density yield prediction for natural stands. Volume over age curves: air approach



APPENDIX 6.Example using TASS to provide yield estimates

In the following example, published TASS managed stand yield tables are used to provide yield predictions for a pure stand of coastal Douglas-fir. The stand originated from planting to 1100 trees/ha. No other stand management practices will occur until harvest at stand total age 70. When determined from Bruce 1981 site index curves, site index is 19.

To obtain TASS yield predictions for this stand, select the appropriate tables from reference (8). First, select the site index table that contains the relevant combination of site index and stand age. This table is reproduced in this appendix (Table A-8). Determine the estimated top height of the stand at 70 years total age. To do this, locate the appropriate site index column (site index 19) in Table A-8. Subtract the indicated years to breast height (10 years) from stand total age (70 years) to obtain breast height age (60 years). The intersection of breast height age (60 years) and site index (19 m) indicates that stand top height is estimated at 21 m at total age 70.

Next, based on management regime, select the appropriate managed stand yield table (Table A-9). This table contains three sections: a volume yield table, a stand and stock table, and a table of culmination mean annual increment and culmination age. In each section, the yield at stand total age 70 is indicated on the row for stands with a reference height of 21 m.

At total age 70, merchantable volume yield is 86 m3/ha to a 22.5 cm minimum DBH. Table A-10 reports the factors by which the estimates of volume and diameter must be multiplied to obtain operational yields. When the operational reduction factors are included, predicted volume yield is reduced to 70 m3/ha. With the operational reduction factors and a 22.5 cm diameter limit, a stand quadratic mean diameter of 25.5 cm is predicted.

The stand and stock table (Table A-9) expresses the predicted yield as the number of stems and total volume per diameter class. This detailed output is essential for financial analyses of stand-level silvicultural alternatives. Figure A-2, reproduced from reference (8), illustrates how stand volume yield (and culmination age) are related to stand total age and site index in this example.

APPENDIX 6. (Continued)

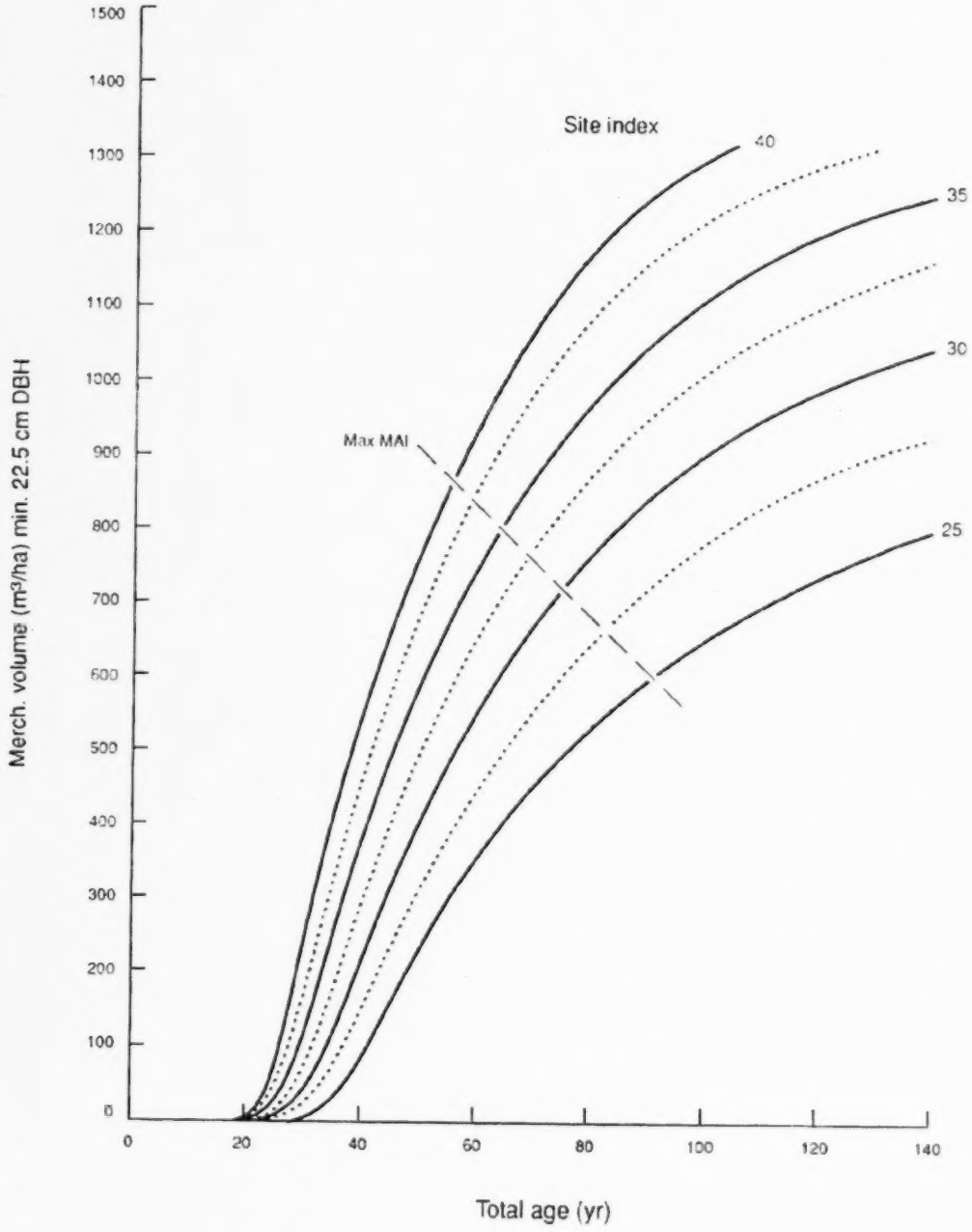


FIGURE A-1. TASS volume-age curves for coastal Douglas-fir planted with 1100 trees per hectare.

APPENDIX 6. (Continued)

TABLE A-4. TASS site index table for coastal Douglas-fir

Age at bh (years)	Breast-height site index (m)															
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	1.7	1.7	1.7	1.7	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.9	1.9	1.9	1.9	1.9
2	2.0	2.1	2.1	2.1	2.2	2.2	2.2	2.3	2.3	2.3	2.3	2.4	2.4	2.4	2.5	2.5
3	2.4	2.4	2.5	2.5	2.6	2.6	2.7	2.7	2.8	2.8	2.9	2.9	3.0	3.0	3.1	3.1
4	2.7	2.8	2.9	3.0	3.0	3.1	3.2	3.3	3.3	3.4	3.5	3.5	3.6	3.7	3.8	3.8
5	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.3	4.4	4.5
6	3.5	3.6	3.7	3.8	4.0	4.1	4.2	4.3	4.4	4.6	4.7	4.8	4.9	5.0	5.1	5.3
7	3.8	4.0	4.1	4.3	4.4	4.6	4.7	4.9	5.0	5.2	5.3	5.4	5.6	5.7	5.9	6.0
8	4.2	4.4	4.5	4.7	4.9	5.1	5.2	5.4	5.6	5.7	5.9	6.1	6.3	6.4	6.6	6.8
9	4.6	4.8	5.0	5.2	5.4	5.6	5.8	6.0	6.1	6.3	6.5	6.7	6.9	7.1	7.3	7.5
10	4.9	5.1	5.4	5.6	5.8	6.0	6.3	6.5	6.7	6.9	7.2	7.4	7.6	7.8	8.0	8.3
11	5.3	5.6	5.8	6.0	6.3	6.5	6.8	7.0	7.3	7.5	7.8	8.0	8.3	8.5	8.8	9.0
12	5.6	5.9	6.2	6.5	6.7	7.0	7.3	7.6	7.8	8.1	8.4	8.7	8.9	9.2	9.5	9.8
13	6.0	6.3	6.6	6.9	7.2	7.5	7.8	8.1	8.4	8.7	9.0	9.3	9.6	9.9	10.2	10.5
14	6.3	6.6	7.0	7.3	7.6	8.0	8.3	8.6	8.9	9.3	9.6	9.9	10.3	10.6	10.9	11.2
15	6.6	7.0	7.4	7.7	8.1	8.4	8.8	9.1	9.5	9.8	10.2	10.5	10.9	11.2	11.6	11.9
16	7.0	7.4	7.7	8.1	8.5	8.9	9.3	9.6	10.0	10.4	10.8	11.2	11.5	11.9	12.3	12.7
17	7.3	7.7	8.1	8.5	8.9	9.3	9.7	10.1	10.5	10.9	11.3	11.7	12.1	12.5	13.0	13.3
18	7.6	8.0	8.5	8.9	9.3	9.8	10.2	10.6	11.0	11.5	11.9	12.3	12.8	13.2	13.6	14.0
19	7.9	8.4	8.8	9.3	9.7	10.2	10.6	11.1	11.6	12.0	12.5	12.9	13.4	13.8	14.3	14.7
20	8.2	8.7	9.2	9.7	10.1	10.6	11.1	11.6	12.0	12.5	13.0	13.5	13.9	14.4	14.9	15.4
21	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0
22	8.8	9.3	9.9	10.4	10.9	11.4	12.0	12.5	13.0	13.5	14.0	14.6	15.1	15.6	16.1	16.6
23	9.1	9.6	10.2	10.7	11.3	11.8	12.4	12.9	13.5	14.0	14.6	15.1	15.6	16.2	16.7	17.3
24	9.4	9.9	10.5	11.1	11.6	12.2	12.8	13.4	13.9	14.5	15.1	15.6	16.2	16.7	17.3	17.9
25	9.7	10.2	10.8	11.4	12.0	12.6	13.2	13.8	14.4	15.0	15.5	16.1	16.7	17.3	17.9	18.5
26	9.9	10.5	11.1	11.8	12.4	13.0	13.6	14.2	14.8	15.4	16.0	16.6	17.2	17.8	18.4	19.0
27	10.2	10.8	11.4	12.1	12.7	13.3	14.0	14.6	15.2	15.9	16.5	17.1	17.7	18.4	19.0	19.6
28	10.4	11.1	11.7	12.4	13.0	13.7	14.3	15.0	15.6	16.3	16.9	17.6	18.2	18.9	19.5	20.2
29	10.7	11.4	12.0	12.7	13.4	14.0	14.7	15.4	16.1	16.7	17.4	18.1	18.7	19.4	20.1	20.7
30	10.9	11.6	12.3	13.0	13.7	14.4	15.1	15.8	16.5	17.1	17.6	18.6	19.2	19.9	20.6	21.3
31	11.2	11.9	12.6	13.3	14.0	14.7	15.4	16.1	16.9	17.6	18.3	19.0	19.7	20.4	21.1	21.8
32	11.4	12.2	12.9	13.6	14.3	15.1	15.8	16.5	17.2	18.0	18.7	19.4	20.1	20.9	21.6	22.3
33	11.7	12.4	13.1	13.9	14.6	15.4	16.1	16.9	17.6	18.4	19.1	19.8	20.6	21.3	22.1	22.8
34	11.9	12.6	13.4	14.2	14.9	15.7	16.5	17.2	18.0	18.7	19.5	20.3	21.0	21.8	22.5	23.3
35	12.1	12.9	13.7	14.4	15.2	16.0	16.8	17.6	18.3	19.1	19.9	20.7	21.5	22.2	23.0	23.8
36	12.3	13.1	13.9	14.7	15.5	16.3	17.1	17.9	18.7	19.5	20.3	21.1	21.9	22.7	23.5	24.3
37	12.5	13.4	14.2	15.0	15.8	16.6	17.4	18.2	19.0	19.9	20.7	21.5	22.3	23.1	23.9	24.7
38	12.8	13.6	14.4	15.2	16.1	16.9	17.7	18.6	19.4	20.2	21.0	21.9	22.7	23.5	24.3	25.2
39	13.0	13.8	14.7	15.5	16.3	17.2	18.0	18.9	19.7	20.6	21.4	22.3	23.1	23.9	24.8	25.6
40	13.2	14.0	14.9	15.7	16.6	17.5	18.3	19.2	20.1	20.9	21.8	22.6	23.5	24.3	25.2	26.1
41	13.4	14.2	15.1	16.0	16.9	17.7	18.6	19.5	20.4	21.2	22.1	23.0	23.9	24.7	25.6	26.5
42	13.6	14.5	15.3	16.2	17.1	18.0	18.9	19.8	20.7	21.6	22.5	23.4	24.2	25.1	26.0	26.9
43	13.8	14.7	15.6	16.5	17.4	18.3	19.2	20.1	21.0	21.9	22.8	23.7	24.6	25.5	26.4	27.3
44	13.9	14.9	15.8	16.7	17.6	18.5	19.5	20.4	21.3	22.2	23.1	24.1	25.0	25.9	26.8	27.7
45	14.1	15.1	16.0	16.9	17.9	18.8	19.7	20.7	21.6	22.5	23.5	24.4	25.3	26.3	27.2	28.1
46	14.3	15.3	16.2	17.1	18.1	19.0	20.0	20.9	21.9	22.8	23.8	24.7	25.7	26.5	27.5	28.5
47	14.5	15.4	16.4	17.4	18.3	19.3	20.3	21.2	22.2	23.1	24.1	25.1	26.0	27.0	27.9	28.9
48	14.7	15.6	16.6	17.6	18.6	19.5	20.5	21.5	22.5	23.4	24.4	25.4	26.3	27.3	28.3	29.3
49	14.8	15.8	16.8	17.8	18.8	19.8	20.8	21.7	22.7	23.7	24.7	25.7	26.7	27.7	28.7	29.6
50	15.0	16.0	17.0	18.0	19.0	20.0	21.0	22.0	23.0	24.0	25.0	26.0	27.0	28.0	29.0	30.0
51	15.2	16.2	17.2	18.2	19.2	20.2	21.2	22.3	23.3	24.3	25.3	26.3	27.3	28.3	29.3	30.4
52	15.3	16.4	17.4	18.4	19.4	20.5	21.5	22.5	23.5	24.6	25.6	26.6	27.6	28.7	29.7	30.7
53	15.5	16.5	17.6	18.6	19.6	20.7	21.7	22.7	23.8	24.8	25.9	26.9	27.9	29.0	30.0	31.0
54	15.6	16.7	17.7	18.8	19.8	20.9	21.9	23.0	24.0	25.1	26.1	27.2	28.2	29.3	30.3	31.4
55	15.8	16.9	17.9	19.0	20.0	21.1	22.2	23.2	24.3	25.3	26.4	27.5	28.5	29.6	30.7	31.7

APPENDIX 6. (Continued)

TABLE A-4. (Continued)

Age at bh (years)	Breast-height site index (m)															
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
56	16.0	17.0	18.1	19.2	20.2	21.3	22.4	23.5	24.5	25.6	26.7	27.7	28.8	29.9	31.0	32.0
57	16.1	17.2	18.3	19.4	20.4	21.5	22.6	23.7	24.8	25.8	26.9	28.0	29.1	30.2	31.3	32.4
58	16.3	17.3	18.4	19.5	20.6	21.7	22.8	23.9	25.0	26.1	27.2	28.3	29.4	30.5	31.6	32.7
59	16.4	17.5	18.6	19.7	20.8	21.9	23.0	24.1	25.2	26.3	27.4	28.5	29.7	30.8	31.9	33.0
60	16.5	17.7	18.8	19.9	21.0	22.1	23.2	24.3	25.5	26.6	27.7	28.8	29.9	31.0	32.2	33.3
61	16.7	17.8	18.9	20.1	21.2	22.3	23.4	24.6	25.7	26.8	27.9	29.1	30.2	31.3	32.5	33.6
62	16.8	18.0	19.1	20.2	21.4	22.5	23.6	24.8	25.9	27.0	28.2	29.3	30.5	31.6	32.7	33.9
63	17.0	18.1	19.2	20.4	21.5	22.7	23.8	25.0	26.1	27.3	28.4	29.6	30.7	31.9	33.0	34.2
64	17.1	18.2	19.4	20.6	21.7	22.9	24.0	25.2	26.3	27.5	28.6	29.8	31.0	32.1	33.3	34.5
65	17.2	18.4	19.5	20.7	21.9	23.0	24.2	25.4	26.5	27.7	28.9	30.0	31.2	32.4	33.6	34.7
66	17.3	18.5	19.7	20.9	22.0	23.2	24.4	25.6	26.7	27.9	29.1	30.3	31.5	32.6	33.8	35.0
67	17.5	18.7	19.8	21.0	22.2	23.4	24.6	25.8	26.9	28.1	29.3	30.5	31.7	32.9	34.1	35.3
68	17.6	18.8	20.0	21.2	22.4	23.6	24.8	26.0	27.1	28.3	29.5	30.7	31.9	33.1	34.3	35.6
69	17.7	18.9	20.1	21.3	22.5	23.7	24.9	26.1	27.3	28.5	29.8	31.0	32.2	33.4	34.6	35.8
70	17.8	19.1	20.3	21.5	22.7	23.9	25.1	26.3	27.5	28.8	30.0	31.2	32.4	33.6	34.8	36.1
71	18.0	19.2	20.4	21.6	22.8	24.1	25.3	26.5	27.7	29.0	30.2	31.4	32.6	33.9	35.1	36.3
72	18.1	19.3	20.5	21.8	23.0	24.2	25.5	26.7	27.9	29.1	30.4	31.6	32.9	34.1	35.3	36.6
73	18.2	19.4	20.7	21.9	23.2	24.4	25.6	26.9	28.1	29.3	30.6	31.8	33.1	34.3	35.6	36.8
74	18.3	19.6	20.8	22.1	23.3	24.5	25.8	27.0	28.3	29.5	30.8	32.0	33.3	34.5	35.8	37.1
75	18.4	19.7	20.9	22.2	23.4	24.7	26.0	27.2	28.5	29.7	31.0	32.2	33.5	34.8	36.0	37.3
Years to breast ht.	11	11	10	10	10	10	10	10	9	9	9	9	9	9	8	8

APPENDIX 6. (Continued)

TABLE A-5. TASS managed stand yield table for coastal Douglas-fir

Stand planted with 1110 trees/ha — untreated (1985)

Cumulative production

Ref. height (m)	Volume (m^3/ha)								Basal area (m^3/ha)	Mean DBH (cm)	Stem count (/ha)	Crown cover (%)	250 Crop trees (12.5+)		
	Gross prod'n.	Total standing		Merchantable									Merch. vol. (m^3/ha)	Mean DBH (cm)	Live crown (%)
	0.0+	0.0+	7.5+	12.5+	17.5+	22.5+	27.5+	32.5+							
0	0	0	0	0	0	0	0	0	0 0	0 0	1110	0	0	0 0	--
3	1	1	0	0	0	0	0	0	0 1	1 2	1058	16	0	0 0	--
6	6	6	0	0	0	0	0		2 6	5 7	1017	60	0	0 0	--
(6)				(UNTREATED)											
9	23	22	22	1	0	0	0	0	7 7	9 9	998	92	1	13 1	69
12	62	60	60	22	1	0	0	0	12 8	12 9	986	96	17	15 5	69
15	111	109	109	83	34	2	0	0	20 0	16 1	979	99	37	19 0	62
18	175	173	173	147	112	26	0	0	26 2	18 5	979	100	62	21 9	52
21	247	245	245	216	197	86	11	0	32 5	20 6	979	100	91	24 4	45
24	326	324	324	293	283	167	44	0	38 4	22 3	979	100	125	26 8	40
27	419	417	417	382	377	294	136	19	45 2	24 3	974	100	164	29 6	36
30	526	523	523	483	479	433	269	112	53 0	26 6	954	100	210	32 4	32
33	651	638	638	597	596	567	444	244	58 6	29 0	888	100	272	35 5	29
36	788	756	756	726	726	707	603	414	64 0	31 6	815	100	342	38 6	27
39	930	860	880	822	822	815	749	576	68 3	34 5	729	100	422	41 6	25
42	1086	955	955	920	920	918	892	759	72 4	37 9	640	100	512	44 5	23
45	1252	1043	1043	1004	1004	1004	997	917	75 3	41 3	562	99	609	47 3	22
48	1422	1127	1127	1085	1085	1085	1085	1072	77 2	44 8	489	96	714	50 0	21
51	1596	1202	1202	1167	1167	1167	1167	1167	79 0	48 3	431	96	827	52 6	20
54	1760	1273	1273	1232	1232	1232	1232	1232	80 1	51 1	390	94	947	55 1	20
57	1918	1342	1342	1310	1310	1310	1310	1310	81 1	54 1	353	92	1074	57 6	19

APPENDIX 6. (Continued)

TABLE A-5. (Continued)

Stand and stock tables (2.5+)

Ref. height (m)	Stem count (/ha)	Merch. vol. (m^3/ha)	Diameter class (cm)														
			5	10	15	20	25	30	35	40	45	50	55	60	65	70	75
12	988			500	479	7											
		38		*16*	*21*	*1*											
21	080			7	190	552	210	20									
		216			*19*	*111*	*75*	*11*									
30	954				40	190	375	230	99	20							
		483			*4*	*46*	*164*	*157*	*89*	*23*							
39	729					27	118	229	158	105	73	19					
		822				*7*	*66*	*173*	*201*	*150*	*146*	*49*					
48	489						12	71	138	111	91	47	12	7			
		1085						*13*	*82*	*240*	*242*	*263*	*158*	*58*	*29*		

Maximum mean annual increment (m^3/ha) and culmination age (years: total age)

DBH limit (cm)	Site index							
	40		35		30		25	
	Max. MAI	Culm'n. age	Max. MAI	Culm'n. age	Max. MAI	Culm'n. age	Max. MAI	Culm'n. age
12.5+	15.1	58	12.2	71	9.2	83	6.3	96
17.5+	15.1	58	12.2	71	9.2	83	6.3	96
22.5+	15.0	59	12.1	75	9.1	85	6.1	110
27.5+	14.7	65	11.8	80	8.3	100	5.4	132
32.5+	14.1	77	10.8	99	7.2	130	4.2	180

APPENDIX 6. (Continued)

TABLE A-6. TASS operational managed stand yield table for coastal Douglas-fir

Merchantable volume and diameter of trees >22.5 cm DBH

Ref. height	Initial density (stems per hectare)											
	4440		2500		1110		750		500		300	
	Vol.	DBH	Vol.	DBH	Vol.	DBH	Vol.	DBH	Vol.	DBH	Vol.	DBH
6	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	18.6	2	21.6	3	22.6	5	23.1	3	24.0
18	4	21.5	2	22.4	21	24.0	36	24.5	41	25.0	40	25.5
21	33	23.8	17	24.6	70	25.5	99	25.5	107	26.2	80	27.9
24	81	24.3	65	24.9	136	26.0	177	26.7	165	28.5	121	31.4
27	177	25.1	179	25.4	240	27.0	260	29.3	231	31.2	167	35.2
30	299	26.3	302	26.6	353	23.7	345	31.0	295	34.3	221	39.0
33	403	28.3	417	28.2	463	30.5	441	33.1	375	37.3	285	42.7
36	517	30.0	529	30.5	577	32.2	543	35.7	466	40.4	355	46.4
39	620	32.3	628	33.0	665	34.9	651	37.9	558	43.2	433	49.9
42	717	35.4	722	35.4	749	37.4	760	40.5	662	46.0	515	53.0
45	802	38.8	798	38.1	819	40.1	846	43.2	754	48.8	602	55.8
48	874	42.0	868	42.5	885	44.8	914	46.5	840	51.6	691	58.4
51	940	45.2	934	45.8	952	48.3	967	49.8	925	54.4	786	60.9
54	996	48.1	1003	49.0	1005	51.1	1025	53.2	1008	57.2	876	63.7
57	1046	50.9	1063	51.7	1069	54.1	1085	56.4	1085	59.9	963	66.3

Operational adjustment factors (see explanation below)

Source	4440		2500		1110		750		500		300	
	Vol.	DBH	Vol.	DBH	Vol.	DBH	Vol.	DBH	Vol.	DBH	Vol.	DBH
Envir.	.850		.850		.850		.850		.850		.850	
DW2B	.960		.960		.960		.960		.960		.960	
Repr.	900	.950	.950	.975								
Net	.734	.950	.775	.975	.816		.816		.816		.816	

Volumes and diameters were reduced by these factors to derive the information in above yield table (i.e., managed stand yield table entry X net factor = current entry). These factors compensate for environmental conditions, decay, waste, and breakage (DW18), and growth repression (i.e., stagnation).